Review - Sustainable livestock systems: anticipating demand side challenges

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Review: Sustainable livestock systems: anticipating demand-side challenges

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ABSTRACT

A sustainable livestock economy depends on both production and consumption, inextricably linked in local, national and global markets. At each scale, technical innovation and production practices need to respond to evolving demand for both market and non-market attributes of livestock systems. This review considers recent and evolving demand-side challenges focussing on emerging preferences related to environmental, dietary and health impacts, arising from both production and consumption. It suggests that these attributes need to be integral to any definition of high-producing animal systems. This discussion is mostly framed using neoclassical economic theory, which highlights market failure and the role of negative and positive external effects or social costs. It examines how our understanding of the demand for these attributes is evolving, leading to market segmentation in some cases, and an existential threat to livestock production as consumption decisions change, investors seek to avoid potential liabilities related to greenhouse gas emissions and potentially antimicrobial resistance, and governments intervene to control other undesirable social costs. The discussion distinguishes between market imperatives in high- and lower-income countries, and how income and consumption trajectories may be less deterministic in a more hyperlinked world where product information may accelerate the evolution of preferences towards and away from livestock products. The review acknowledges the limits of a neoclassical approach, drawing attention to more fundamental concepts of biophysical limits to growth and value pluralism, which indicates values (e.g. intrinsic) that lie beyond the neoclassical framing of demand and value.

Implications

Livestock systems make positive and negative contributions to society arising from production and consumption. These effects depend on location and specific economic and cultural contexts, and some are not apparent in market transactions and therefore consumption decisions. Correcting this market failure implies valuation of these impacts and consideration of how these values can be used as signals in the design of more sustainable systems. Most attention to date has focussed on improved production. This paper takes a consumption or demand-side perspective and considers the role of private consumer and wider public preferences in the likely evolution of future livestock economies.

Introduction

While livestock production and meat consumption can be traced back to the earliest eras of humankind, their predominance or immutable status in food systems and human diets is increasingly contested (Guardian, 2020). Historical analysis suggests there is nothing inevitable about meat consumption as either a fixed social norm, or a necessity for human nutrition, or for agricultural sustainability. Instead, meat's status reflects the myriad cultural contexts in which it is socially constructed in people's everyday lives, particularly with respect to religious, gender, communal, racial, national and class identity (Chiles and Fitzgerald, 2018). Recent arguments to buttress the sector have invoked food security, mostly in low-income contexts, food sovereignty, and culinary patriotism. These notions have been reinforced and encouraged by a sector lobby that maintains a narrative that meat and livestock are natural, normal, necessary and even nice (Piazza et al., 2015). The same lobby can wield significant political power in some countries, capturing government support and stifling debate about agricultural transformation. As we gain a better understanding of the roles of meat in human diets, and of livestock in wider global environmental change, this transformation agenda is becoming more urgent, with obvious implications for the focus of livestock science.

This review does not adjudicate on what is a complex and apparently unresolved multidisciplinary debate around dietary

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evolution (Turner and Thompson, 2013), nor whether livestock needs to be part of sustainable farming systems or socially desirable landscapes. Instead, it recognises the diverse nature of current livestock production systems and of current meat consumption, and explores the changing nature of public preferences for both, considering the associated market and non-market attributes. It acknowledges the differing developmental hence demand imperatives in low- and upper-income countries, and considers how keeping livestock may in some cases be an important stage in a pathway out of poverty. The nature of demand is initially explained with reference to neoclassical economic theory, which provides a framework for understanding the relationship between preferences, demand and value of different products in any market (Deaton and Muellbauer, 1980). It also explains why markets fail and how this failure might notionally be corrected by valuing externalities and judicious regulatory intervention (Freeman et al., 2014). A neoclassical framing is contested and is, for some, fundamentally anthropocentric and reductionist. Alternative critiques will be referenced, as they point to more universal notions of planetary boundaries, and the legitimacy of other non-instrumental values that lie beyond the anthropocentric utilitarian (i.e. neoclassical) framework.

This review considers terrestrial livestock but recognises that many of the problems of market failure are becoming more conspicuous in aquaculture (Hilborn et al., 2018). The review follows a variety of papers signalling the emerging livestock sustainability challenges (Buckwell and Nadeu, 2018; Sahlin et al., 2020), and how policy might tackle production and consumption challenges (Bonnet et al., 2020; Pieper et al., 2020). It complements other papers offering more detailed analysis of consumption and global trade trends and regulatory policy for public goods (e.g. Revell, 2015) including papers in this issue (Guyomard et al., 2021; Chatellier, 2021; Henchion et al., 2021).

We initially recap on global consumption trends and the nature of demand as represented in theoretical terms, and as a basis for empirical estimation. The discussion distinguishes between demand for market and non-market goods. The third section distinguishes the different developmental contexts of farming systems and livestock production and consumption to understand the different weights placed on market and non-market attributes. Subsequent sections consider market, non-market and cultural factors that may accelerate evolving consumption trends, and whether and how the private sector can respond to these demands and the likely evolution of government intervention through potential voluntary, mandatory, market-based approaches to realign production with consumption preferences. Later sections provide discussion and a conclusion.

Livestock systems

An expanding global middle class is driving dietary convergence and global meat consumption. Average annual per capita consumption was 25 kg in 1961 rising to 48 kg by 2013 (FAO, 2018), and projected to increase between 75% and 145% by 2050 (Godfray et al., 2018). These figures mask varying transitions across high-, middle- and low-income countries. The US still has the highest annual per capita consumption at 100 kg, while the EU average is around 71 kg. Growth in consumption is slowing across most high-income countries. China accounts for around half of global consumption, projected to grow till 2030, with current per capita consumption around half that in United States.

Providing this meat and other animal products, there are about 30 billion livestock animals in the world at any given time, four times the number of humans. Over 160 billion livestock are slaughtered annually, half of these are poultry (FAO, 2018). Animals are raised in a variety of systems co-evolved with local economic, biophysical and cultural conditions (Robinson et al., 2011). These range from extensive pastoralist and transhumance, through mixed crop-livestock systems, to more intensive and housed systems. In industrialised economies, and for upper-income households in all countries, the characteristics of these systems (real and perceived) are important joint product attributes, and increasingly an element of market segmentation in the ultimate consumption decision. For example, grass-fed, extensive and organic systems are attractive 'natural' production attributes commonly communicated to match consumer preferences. In lower-income contexts, system attributes are more directly related to consumption needs and household livelihoods.

Meat demand: market and non-market dimensions

Demand can be explained by rising incomes related to economic growth, implying that a significant global population will transition to higher meat content in diets, although the composition may change. In many developed countries, meat, dairy and wheat products provide the major sources of protein availability, and in some countries, the composition of meat demand has progressively switched from bovine meat to pig meat and poultry. This switch is likely to be the case globally by 2022 and is explained by a combination of relative product prices and lifestyles. The global nutrition transition still leaves many countries accounting for high bovine meat demand.

Income is the key economic driver explaining the nutrition transition, with some commentators speculating an inverted U-shaped relationship over time and across countries (Vranken et al., 2014). Accordingly, lower-income countries are associated with a positive income elasticity of demand, meaning that increasing incomes lead to higher meat demand (Gallet, 2010). At a certain income level, country-specific 'peak meat' is reached, beyond which higher income is associated with lower demand or an implied negative income elasticity. In empirical demand estimation, other explanatory variables (of meat demand) include own price, and cross-price elasticities (the percentage change in product demand due to a change in price and quality of a substitute good), which increasingly includes meat substitutes and other lab-grown products.

Market demand can be segmented by identifiable consumer preferences for different production and consumption attributes that can be both market and non-market. Market demand attributes are largely reflected in observable prices and are mostly driven by traditional quality and credence (i.e. not immediately observable) attributes specific to the product as observed at the point of purchase (Henchion et al., 2014). Perceived quality is multidimensional, based on sensory (eating enjoyment), safety, healthiness and convenience. At the point of purchase, important consumer quality cues can be promoted by so-called extrinsic messaging such as quality labelling, use-by dates, place of purchase and product origin information, as well as production and processing attributes. The latter includes organic and welfare-friendly production and possibly other environmental information. In the case of welfare and environmental cues, there is an overlap with the non-market demand attributes.

These and others (e.g. biodiversity friendly) may not be easily signalled and therefore transacted in product attributes or detectable in an observable market transaction. Importantly, even if these attributes are signalled in the private product, they are essentially provided to everyone, whether or not they are a meat consumer.

Market and policy failures

The increasing awareness of non-market attributes draws attention to the notion of market-failure. That is, routine transactions (and hence the market) typically fail to supply the right or socially optimal quantity of a non-market attribute. Non-market attributes include animal welfare (both credence and non-market), and associated production methods and systems, system pollutants including greenhouse gas (**GHG**) emission mitigation, animal health (e.g. preventable zoonosis), and wider concerns about the preservation of ecosystems, landscapes and cultural attributes of livestock. Many of these values pertain irrespective of any direct interaction inside or beyond markets. Thus, I may value e.g. a rare Spanish breed of bull without ever seeing it and there may be no market for its products or services unless I like bullfights.

Non-market values can be further categorised into indirect value, option value and existence value, which can reflect preferences held by livestock owners, meat consumers and non-consumers. Elaboration of these value categories need not detain us here (see Bockstael et al., 2000). Suffice to say that there is much academic effort to improve their measurement so that they may be included in the market and factored into policy decisions (e.g. regulatory) affecting producers and consumers. By getting these prices 'right' (i.e. correcting market failure), systems can theoretically be optimised with minimal intervention.

In practice, market failure explains a significant gap between what many producers do and what consumers and society want. Trying to correct this disparity is complex because it theoretically implies many private agents seeking information on preferences and contracting individually for their preferred outcomes. In economic jargon, this amounts to a condition of prohibitive transactions costs, rendering the exercise impractical from a social perspective. Instead, there is a rationale for government intervention to address the under-supply of so-called public goods for all users (consumers and non-consumers of meat), and to help minimise external costs. However, this regulatory task is complicated by at least two factors. First, government policy design, for example to fix statutory levels of animal welfare, must contend with the incomplete information about production costs and changing consumer preferences. This means that well-intended government objectives can sometimes fail to deliver efficiently, largely due to similar transaction cost reasons previously mentioned. Second, some preferences may be motivated by an appreciation of intrinsic value, which recognises inalienable rights of animals to exist irrespective of human preferences. Such preferences, which can be held by a significant proportion of the public, do not align with the calculus of the aforementioned market and non-market values. The aim of this paper is not to explore the nature of intrinsic value, beyond stressing that it is largely incommensurate with the neoclassical prescription of correcting market failure through valuation. This issue frequently arises in the context of discussion of the ethics of genetic modification and animal welfare (Johansson-Stenman, 2018).

Often poorly articulated, the evolving significance of non-market dimensions and the intrinsic value arguments are the crux of most of the global rhetoric about the future of livestock. These factors are increasingly in play in consumption decisions, taken in a context of increasing consumer information through improved hyperlinked marketing, the role of pressure groups and influencers, and new lifestyle trends. All conspire to generate different (increasingly negative) messages about meat and related production systems. The following sections scrutinise system external cost in terms of metrics, and in relation to their influence on consumption decisions in developed and developing countries.

Clarifying consumption externalities

We outline terminology related to market failure to bring clarity to discussions about livestock futures. Economic theory treats environmental costs as 'environmental externalities', (or 'hidden' costs) (WWF, 2020), which can be overlooked in (or distort) observable market calculus. Optimizing social welfare when externalities are present means correcting the prices faced by economic agents (Varian, 1992). Many externalities arise from production practices, which in turn respond to notional consumer demand.

The most important defining characteristic for externalities (positive and negative) is that it is difficult to be excluded from the incidence or impact. This includes the possibility of others benefiting from my private purchase decision of a product with a prosocial attribute. Positive externalities are a characteristic of many public good services, such as defence, education, health, which typically have to be supplied by government. When markets fail, governments also seek to regulate good and bad externalities through promotion of voluntary or mandatory compliance measures (e.g. on pollution levels), sometimes termed command and control approaches. Alternatively, more sophisticated market-based measures such as pollution pricing or trading can also be applied (Steinebach, 2019).

Irrespective of sign, it is important for policy to clarify liability for the externality, and who should pay whom for its incidence or the infringement of rights not to suffer negatively, which are either common property (we all a stake) or private. Recalling that many externalities are non-excludable, a particular problem is the mix of incidence that can affect private agents and/ or be globally public (transboundary). We examine this further with emphasis on consumption externalities.

Consumers consume the products of livestock systems directly, indirectly and in a passive or non-use way. These distinctions help to delineate the following sections that describe different elements of consumption and specific external costs. In some cases, the externality is specific to the actual consumption decision, while in others, it is derived from the demand which entails a specific livestock production system over which the consumer has no direct control (i.e. at the point of purchase) other than to abstain from the market.

Diet and health

Accumulating evidence in health studies and focussing on healthy diets have highlighted the effects of consuming red and processed meats, and the need to moderate the consumption in westernised diets. Red and processed meat consumption is positively associated with all-cause mortality (Rohrmann et al., 2013), and with weight gain. The alarm is that the planetary health burden will escalate with rising consumption without dietary constraints. The market failure relates first to a lack of nutritional and dietary information and private underestimation of the health effects of unbalanced consumption. This private cost is typically externalised onto other parts of society, particularly resource-constrained public health systems.

More recent variants of planetary diets (Willett et al., 2019; Scheelbeek et al., 2020) are more discriminating between the impacts of red and processed meats and also point to joint health and environmental outcomes from modified meat consumption. The effectiveness of prescribed diets is contested in terms of measured health effects and their normative nature. That is, they typically overlook the ability of low-income groups to access the key food groups (Chungchunlam et al., 2020).

There is nevertheless a growing consensus and emerging social norm that moderated meat consumption in high-income countries

has to play a role in meeting both dietary and environmental targets. This consensus will be slower to evolve in lower-income settings where nutritional needs are met from livestock sources due to restricted dietary options. There is no consensus that these regions will follow the dietary trajectories observed in OECD countries.

Greenhouse gas emissions

Greenhouse gas emissions are the most conspicuous global externality associated with the livestock economy. Emissions of methane and nitrous oxide, and to a lesser extent carbon dioxide, have truly global external impacts, described as the greatest market failure ever (Stern et al., 2006). These emissions are an inevitable consequence of extensive land use change for livestock cultivation across the world. They come directly from the animals themselves, and indirectly from land use change for pastures and cultivation of other feeds, food processing and waste. Emissions are projected to grow in relative terms as an overall share of the emission envelope (or budgets) of many countries. This is because the sector is currently unregulated in the same way as other significant sources of industrial emissions. If this continues, ruminant meat may be responsible for around two-thirds, and animal products for 80%, of global GHG emissions from agriculture by 2050 (Hedenus, Wirsenius and Johansson, 2014; Tilman and Clark, 2014).

Reducing the emissions-intensity (GHG per unit product) is an increasingly important focus for livestock science and is now central to any definition of high-producing animals. Scientific consensus on the consumption imperative is clear in Intergovernmental Panel on Climate Change IPCC (2019), which states with high confidence that balanced diets featuring plant-based and sustainably produced animal-sourced food '*present major opportunities for adaptation and mitigation while generating significant co-benefits in terms of human health*'. As livestock become increasingly implicated in the climate crisis, we can expect consumers to become more aware of the relative emissions-intensity of their purchasing and consumption decisions. This information is currently conflated with other environmental and dietary narratives. While some consumers can discriminate between the emissions-intensity of ruminants vs poultry, it is not obvious that they can yet discriminate between relatively emissions-intensive ruminant systems, for example, the argument of some being relatively emission neutral in some parts of the world.

The existence of a carbon price means that this market failure is being addressed in sectors covered by mandatory or voluntary carbon credit systems. Debate continues about whether and how these might extend to livestock and meat consumption emissions, pending resolution of some outstanding issues, including the relative life cycle costs of meat and meat alternatives, the accuracy of direct measurement of animal emissions, and resolving the responsibility and thus the point at which any price should be paid - e.g. by producers or consumers. Research on consumer willingness to pay full carbon costs in product prices is mixed (Li et al., 2016). Camilleri et al. (2019) suggest that consumers generally underestimate the emissions-intensity of food products and that better labelling could help direct choices.

Other demand-side measures to influence consumption include advertising campaigns, meat-free days, modified portion sizes and menu editing or replacement with meat alternatives, including insects and cultured meats. Some of these measures are currently encouraged in private and public feeding systems, for example, through public procurement for schools and other public bodies. An obvious evolution is that edited food choices offered in these contexts will facilitate preference formation and meat-free choices that are retarded by the need to make a personal choice to restrict consumption. Other personal choices include adoption of flexitarian, vegetarian and vegan lifestyles.

Biodiversity and ecosystem services

Livestock production is arguably one of the most significant drivers of historical global land use change, including landscape production. Due to the variety of systems, it is difficult to generalise about the combined ecosystem footprint, including both negative and positive impacts that arise largely due to the way animals are reared. We can think of this as a process of transition through initial land use and possibly clearing for extensive production, to the evolution of more managed landscapes in which livestock themselves become quintessential ecological and cultural components as heritage or rare breeds.

Intermediate stages of transition can give rise to different ecosystem impacts and services that are currently debated as attributable to livestock. On the positive side, beyond market products, livestock contribute to soil and grassland health and fertility, and the potential for biomass in some grassland systems to offset global emissions (Zubieta et al., 2020). There is currently some debate about whether this sequestration approach can be upscaled to meet the objective of carbon neutral farms. In smallholder subsistence context, benefits include the use of animals for draught and grazing services, and reuse of animal waste can be crucial for sustainable livelihoods particularly in environments where alternative sources of inputs such as fertiliser and energy are scarce, and where animals are a savings vehicle and eventually a ladder out of poverty. A more technocratic extension of this transition places livestock within the systemic circular economy frame, where animal products (waste in particular) have traditional and novel uses as inputs into other productive processes such as energy generation.

Beyond GHGs, negative impacts are related to soil and water use (quantity and quality). Concepts such as a water footprint and virtual water have been developed as indicators of water sustainability relevant to both producers and consumers (Velázquez, Madrid and Beltrán, 2011). Technically, the value of water is widely estimated, with supply costs and often (but not always) paid by producers with some part passed onto consumers. Arguably, there is less of a market failure. To date, labels signifying water scarcity and value do not feature prominently in many product labels and it is again unclear what priority they receive at the point of purchase.

A more significant market failure relates to the irreversible and unsustainable loss of biodiversity and ecosystem services in primary ecosystems e.g. in emblematic tropical forests. This stage is arguably a social cost that is traditionally not internalised by producers, while consumers currently have limited market channels to express preferences either through direct product choice or indirectly through the purchase of targeted carbon offsets or credits. Supply chain transparency initiatives such as TRASE (https://trase.earth/) are working to clarify supply chain sources contaminated by illegal livestock-related deforestation. The use of geospatial 'big' data, artificial intelligence, with deep learning (Lamba et al., 2019), and potentially block chain ledgers all offer the potential to improve consumer visibility of production systems.

While the livestock-land transition to grazing systems can be synergistic with soil and grassland biomass accretion, it is typically antagonistic to indigenous biodiversity. However, the ultimate transition to managed landscapes creates a new value dynamic where livestock typically become part of a cultural mosaic that includes their amenity, cultural and existence value. Globally, these transitions are happening at different stages, and there is no sense in which they balance or cancel out. Different livestock systems create different dynamics, their ecosystem values being more or less significant for consumption decisions.

Metrics for understanding, valuing and internalizing these ecosystem service impacts have evolved in the last thirty years, culminating in an Ecosystem Services Framework for reconciling, quantifying and valuing service values across the spectrum of supporting, provisioning regulating and cultural services (MEA, 2005). While some service values are private (e.g. provisioning services), the public good nature of others is recognised by a variety of policies that support their supply by direct payment, either from government or through more innovative market-like transactions as payment for ecosystem services (**PES**). Most PES deals are between intermediate supply chain actors, but some may be more directly relevant to final consumer products through the use of labelling for Protected Designation of Origin, and support for rare and heritage breeds and products carrying Rainforest Alliance and other certification. Overall, the extent of market information available to consumers is often inconsistent and difficult to interpret.

Animal welfare

Animal welfare is a longer-standing concern for consumers and more proximate in terms of cognition and appreciation. It is nevertheless both a public and a credence good, and market failure arises because consumers do not observe and purchase it directly, but as a credence attribute defined by labels that are backed by regulatory standards and freedom criteria. These in turn communicate information about the production system and the adherence to best practice. There is much to debate about the consistency of labels and consumer perceptions of what they represent, but technically, the welfare segment is a strong and established niche backed by judicious government regulation that is increasingly marketed across different countries and for which consumers are willing to pay.

Numerous stated preference studies (contingent valuation and choice experiments) focussing on welfare attributes have highlighted the explanatory role of income (Lagerkvist and Hess, 2011). Although hypothetical surveys come with caveats, the evidence would suggest a positive income elasticity of willingness to pay, which suggests that global demand for welfare will increase as countries will graduate to higher income brackets. Arguably, the status of welfare labelling is a route map for other credence attributes. What remains to be tested is the cognitive burden of multiple labels (e.g. welfare, plus carbon plus biodiversity) on a single product.

Genetic modification and biotechnology

Increased use of biotechnology is a potential route for reducing the external cost of livestock production, combining molecular, quantitative and statistical genetics, reproductive biology, and precision agriculture. However, most consumers are unsighted as to the relative merits of these interventions and there is currently no obvious product niche. When deploying and communicating the advantages of these technologies, the livestock sector is also arguably suffering from a legacy of poor communication of the benefits and cost of genetically modified crops. That experience left an impression that genetic technologies conflicted with preferences for naturalness and the intrinsic value of species. It also cast the advocates of genetic technologies as being in the pay of powerful multinational corporations seeking to patent or otherwise appropriate commonly held genetic materials for private gain. Taken together, these were significant barriers that still prevail. In terms of sustainability, the full extent to which these technologies can be deployed to meet specific public good objectives such as the removal of GHG emissions from production remains unclear.

To win consumer acceptance, one lesson is to be candid and open rather than either assuming that the benefits are obvious or that product can pass seamlessly into supply chains. Giving consumers agency over their choices is important, as is perceived control of the technology and careful messaging on the private vs public or social benefits accruing from its acceptance. For example, public acceptance seems more likely when highlighting associated clinical discoveries that have emerged from e.g. gene transfer that could equally be applied into more social (rather than private) ends including food systems, reduction of GHGs and the avoidance of extinction through *ex situ* storage of genetic materials. Other social benefits associated with gene editing applications include disease resistance, animal welfare, production traits, animals as bioreactors, xenotransplantation and the development of models for human diseases (Van Eenennaam and Young, 2018). Emphasis of social benefits is more likely to align with the preferences of a new generation of consumers for whom these issues outweigh claims about superior meat quality. In the same way, the marketing of genetically modified products is located on a spectrum between 'conventional' meat production at one extreme and lab-grown meat at the other.

Meat-free alternatives

The combination of environmental and consumer health concerns have motivated the research, development and marketing of substitute non-meat products (Post et al., 2020). Meat analogues include cultured meat (also referred to as clean meat, in vitro meat and lab-grown meat), which is produced through tissue engineering techniques, and plant-based meat which is constructed from proteins extracted from plants. In addition, fungi-based meat alternatives such as Quorn™ products and insect-based meat products have been marketed. Processed fungi-based meat products have been available on the retail market for decades. Similarly, plant-based meats options such as Beyond Meat and Impossible Foods are increasingly found on supermarket shelves and restaurant menus. A recent breakthrough is that Singapore has given regulatory approval for the world's first 'clean meat' grown from animal muscle cells in a lab.

Despite optimistic market sizing and investment scenarios, these analogues face their own regulatory challenges in terms of safety, consumer acceptability, scalability and general health benefits and sustainability of products when considered from a full life-cycle perspective, and in terms of what consumption they are actually displacing (e.g. meat or other plant-based foods). As with other new products, cost, intrinsic and extrinsic product attributes and societal norms (see below) will drive demand, which is likely to vary across consumer segments. To date, there appears to be a focus on product similarity at the point of purchase and seemingly less research on the acceptability in different meal types or when framing the purchase decision around the broader environmental or cultural perspectives. This includes a consideration of what a 'new meat' bio-economy looks like, and the likely consequences of converting conventional farming to a system of agroecological symbiosis combining agroecological farming practices, biogas production, and cellular agriculture.

Food waste

Using Food and Agriculture Organisation data, Alexander et al. (2017) show that almost half of the harvested crops – or 2.1 billion tonnes – are lost through over-consumption, consumer waste and inefficiencies in production processes. Livestock production is the least efficient process, with losses of 78% or 840 million tonnes. Some 1.08 billion tonnes of harvested crops are used to produce 240 million tonnes of edible animal products including meat, milk and eggs. This stage alone accounts for 40% of all losses of harvested crops.

Consumer awareness of this inefficiency and preferences for avoiding food waste have increased greatly in the light of such evidence, including the fact there is only so much that can be achieved through improvements to feed use efficiency or on retailers' or consumers' own ability to minimise loss at later stages of the food chain. A simple conclusion is to reduce meat consumption in favour of grain consumption, although it is unclear what priority the waste reduction has in consumer purchasing decisions.

Political economy and market power

The cognitive burden that consumers face includes a more general apprehension of the fairness and ethics inherent in the institutions that produce and supply food. In many OECD countries, the institutional arrangements around livestock are dominated by powerful transnational corporations wielding power in input and product markets including feed and veterinary health. This power extends to the lobby of state governance structures to influence regulations in relation to production practices and labour relations. For some commentators (e.g. Weis, 2013), this should be understood together to comprise a powerful long-term vector of global inequality and wider loss of resilience. Meanwhile, an evolved oligopolistic retailing structure is perceived to work against consumers and farmers. For many consumers, these facets of industrialised food systems are conflated into a single image of rapacious land use change, biodiversity loss, zoonoses, and now, pandemics.

From a political economy perspective, the power relations are generally stacked against smaller supply chain actors and consumers. Although consumers may recognise the diversity and resilience of modern dominant feeding systems, they may also express disquiet and a preference for transparency and shorter or more localised food. Although this notion is often romanticised, there is definitely an evolving demand for more local produce that reduces food miles and that somehow fosters a more intimate and trusting relationship between consumers and producers.

Emerging liabilities and corporate compliance

Incipient environmental and health liabilities are another evolving demand-side trend threatening the viability of livestock systems. Liability for GHG emissions across a variety of industries is coming into sharper focus as institutional investors, banks and insurers seek to minimise their exposure to climate risks. This pressure is likely to translate into an indirect demand for a lower impact livestock sector as companies respond to investor pressure (FAIRR, 2019).

The global pension fund industry controls trillions of dollars invested in listed corporations on behalf of a wider public. In the United States alone, pension fund assets under management are worth around $9 trillion, dwarfing the meat market worth $74bn (FT, 2019) or $1.3 trillion globally. These assets are vulnerable to three major categories of climate-related risk: (i) climate impact risks hitting vulnerable listed companies and thus exposing those invested in them, (ii) carbon-constrained demand risks – i.e. where a business model is heavily dependent on hydrocarbon inputs, and (iii) climate liability risks, where company emissions are implicated by damaged parties. Typically acting under customer and activist pressure, investors are seeking to withdraw funds from investments at risk, and this includes the agribusiness/livestock sectors.

Like institutional investors, commercial and investment banks and insurance companies are also alert to exposure to incipient risks and liabilities. Recognizing this risk, central banks and financial regulators are also giving advance warnings on how regulated lenders can work with investors to increase business plan transparency from the beginning (Bank of England, 2019). Insurers are seeing the potential risks in potential subrogation claims. This is when insurance companies pay their policyholders for damage and then 'stand in the shoes of the insured' by seeking compensation from the third party that caused the damage in the first place.

There are no current test cases implicating livestock, although the legal pathways are being clarified for litigation in some jurisdictions (Walters, 2019). Fig. 1 shows a rising trend in litigation and thus this risk is not just theoretical and could potentially extend to other liabilities such as antimicrobial resistance, a challenge that has some similarity to GHGs in terms of animal sources, global damages and potential liabilities related to uncontrolled use of antibiotics. Ultimately, it is conceivable to see a stranded assets narrative emerging for livestock similar to that retarding the exploitation of fossil fuels.

Carbon pricing is increasingly being talked about in financial and investor circles as the most effective method to incentivise companies. Some corporations already report carbon-adjusted performance measures. For example, Danone uses a metric termed the carbon-adjusted earnings per share, which deducts a carbon cost of €35 per tonne (multiplied by total emissions) from its share value. This recently showed that the company's headline 2019 earnings per share would have fallen from €3.85 to €2.38, a decline of 38%. This is essentially an adjusted growth measure giving the company an internal incentive to drive emissions out of all its supply chains rather than passing the liability onto consumers.

If other ecosystem services/impacts can be valued monetarily, there is no reason not to extend the adjustment beyond carbon. An evolving trend is that the ecosystem service agenda is being incorporated in corporate natural capital accounting tools as share price or other balance sheet adjustments that signal true shareholder and stakeholder value. Where once corporate reporting could maintain a qualitative narrative on corporate social responsibility, there is now an evolving trend towards monetary quantification. Where these things are quantified, they rarely revert to being reported by qualitative narratives.

Regulating consumption: market vs policy

The market can only guide optimal consumer choices to a limited extent, and, in the case of liability and corporate performance, only indirectly. Market failure and external cost from meat consumption raise an issue of the level of possible government intervention to regulate or otherwise nudge consumption choices (Katare et al., 2020). There is no global governance structure to regulate transnational food supply chains and most livestock externalities are currently only regulated indirectly by a variety of national policies focussed on production (mostly subsidy) and consumption (mostly government advice on health). The only potentially feasible transboundary policy instrument is the application of carbon prices (taxes or tradeable permits) that currently apply to other major emitting sectors. To date, specific challenges around monitoring, verifying and reporting life cycle emissions, combined with powerful lobbying, mean that agricultural emissions remain outside of any formal market-based system such as the European Union Emissions Trading System. While this is the case, there is no mandatory market signal that could potentially be passed from producers (the direct polluters) through to consumers. This means that voluntary regulation is the default with governments fostering industry and farmer collaborations for innovation and uptake of good practices. Notwithstanding a general lack of evaluations of the performance of these initiatives, there is a general perception that the agri-food sector is not making sufficient progress in contributing to national targets on low or carbon neutrality. This situation is largely unsustainable and there is increasing scrutiny of

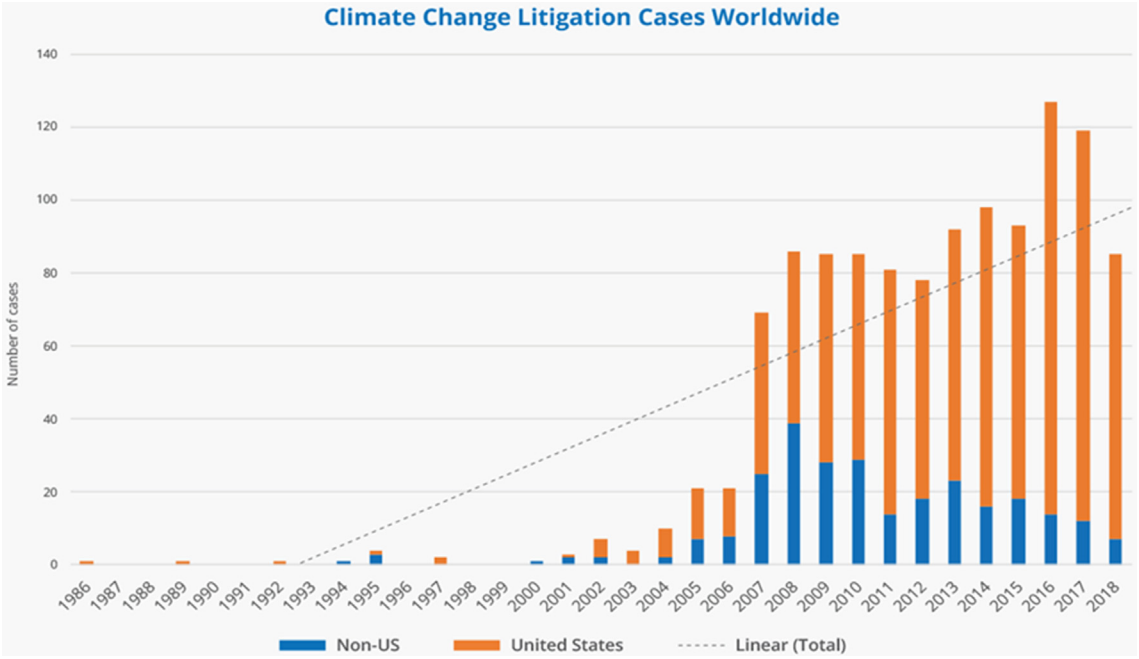

Fig. 1. Climate change litigation cases worldwide. Source: https://www.carbon-delta.com/climate-change-a-growing-liability-for-companies-and-investors/ (accessed 18th October 2020).

agricultural emissions (FT, 2021). Combined with the pressures of legal liability, the carbon pricing pressure is the most likely externality pricing (or internalisation) scenario that can be envisaged.

Table 1 summarises a variety of measures that can influence demand-side behaviours combining market and government interventions. Broadly, these are either voluntary advice or guidance, mandatory measures, and market-based instruments. While mostly implemented by government, some measures such as labelling and information on product sustainability credentials can be introduced independently of mandatory measures. This may be the case, for example, as manufacturers and retailers seek a competitive advantage in product niches. In relation to meat consumption, there has so far been little direct intervention beyond local authority decisions on procurement and the encouragement of meat-free days or choice editing menus in public sector organisations. Policy is largely in the voluntary category, with an aversion to stricter regulation of consumer choice.

Social norms and scenarios

New policies can precede or follow and confirm the emergence of new social norms. Economic theory is often supposed to be about individuals selfishly maximizing their preferences, when in fact preferences can overlap. I may care that you care about my consumption of meat. I may care enough to alter my behaviour. Enough people acting in a similar way leads to a group or social norm. Recalling changed norms with regards to smoking, drink-driving, flying or wearing face coverings, we can see that these can come about rapidly and typically are rarely if ever reversed.

There is some evidence on the developing social norms and removal of barriers to the birth of social norms in the literature – some of it about animal welfare (Delon, 2018). Market research suggests increased adoption of flexitarian (i.e. reduced meat content) diets in western industrialised countries, and with respect to the market penetration of plant-based products and lab-produced meat substitutes particularly among a section of early adopters. However, there is less evidence of any critical inflection or tipping point in relation to the adoption of vegetarianism and vegan lifestyles. In recent modelling, combining behavioural intentions and likely environmental outcomes, Eker et al. (2019) suggested that emerging social norms among young people (ages 15–44) was the parameter that contributed to most variance in the outcome. This supports earlier findings that values endorsed by the peer group have more influence on whether people make a change than actual health and climate risks. Further, the authors suggest that when it comes to reducing climate impact, it is more effective to persuade a majority to move from regular meat-eating to a flexitarian diet than for a smaller group to abandon meat altogether. This strategy accords with the fact that many campaign groups have found it daunting to promote a message of full abstinence compared to one that affords some agency with target populations (Laestadius et al., 2014).

Discussion

Driven by incomes, concerns about planetary change and dietary awareness, the global convergence on meat consumption is happening at different rates and from different starting points. An income-consumption relationship suggests that many upper-income countries are beyond a turning point where income elasticity of demand is negative. In these countries, meat consumption is increasingly a niche in a segmented market that includes consumption of high-end products and meat substitutes. This is partly encapsulated in a rhetoric of eating less and better, with Sahlin, Röös and Gordon (2020) recently highlighting the contested and often conflicting definitions for both these terms.

Other lower-income countries are still on an upward trend, i.e. rising income is associated with increasing demand, but the rate of change is declining. Given the diversity of intervening region-specific cultural factors, there is no fixed trajectory for low-income countries to follow, and livestock demand is likely to remain significant in diets with several demand segments reflecting national and regional cultural specificities and relative preferences for market and non-market attributes.

The corresponding global production scenarios will likely reflect the emerging demand segments (meat, meat substitutes and no

Table 1
Consumption/demand-side measures following from the neoclassical framing of external costs.

Instrument/incentive/ externality targeted	How it works	Challenges	Examples
Taxes on carbon intensity	Enacts the Polluter Pays Principle establishing direct link between the GHG emissions (measured in metric tonnes of carbon dioxide equivalent or tCO2e) of a product or process and the tax that must be paid on it.	Revenue neutrality and revenue recycling might be necessary to generate joint climate and health outcomes. Taxes often posited as an alternative to tradable permits. Leakage is another potential problem.	See Revoredo-Giha, Chalmers and Akaichi (2018), World Bank (2017)
Taxes on fat/sugar content	Similar to carbon tax but targeting content.	Effects depend on own and cross-price elasticity, the extent of pass through to consumers, and distributional incidence.	Härkänen et al. (2014)
Subsidies and cash incentives to promote consumption of 'healthy' foods	Lowering the cost of and ability to access healthy foods to increase their consumption.	Subsidies relatively straightforward to implement but suffer a time-lag of delayed gratification. Society pays an expensive price up front for a later benefit, when the number of overweight people had been reduced.	Afshin et al. (2017), Flores and Rivas (2017))
Carbon border tax	Carbon border adjustment mechanism for selected sectors, to reduce the risk of carbon leakage. This would ensure that the price of imports reflects more accurately their carbon content.	Making border tax adjustments compliant with World Trade Organisation law. Extent of pass through to consumers and distributional incidence also relevant consumption choices.	Beattie (2020)
Public procurement for carbon neutrality and dietary outcomes	So-called hard paternalism. Mandated supply sources for public sector incl. school catering to lower life cycle emissions and to nudge health choices.	Political will to modify procurement rules and to set clear specifications on supplies, the availability of verified low emissions supply chains for certain foods.	Cerutti et al. (2016)
Public health promotion of 'healthy' foods/diets	Public messaging on recommended dietary composition including meat components.	Bridging a gap between the notionally optimal diet and what target (esp., low income and marginal) consumers can actually afford. May need to be combined with targeted subsidy.	Vaillancourt et al. (2019)
Restrictions on advertising	Restricted product advertising on foods high in sugar and fat – particularly children during specific viewing times and specific locations.	Leakage into other advertising outlets - can social media be regulated?	Dhar and Baylis (2011)
Product labelling/ Sustainability certification	Mandatory and voluntary product labelling to signal quality, credence and other 'footprint' information.	Multiple labels competing for consumer attention and some doubt about whether labels actually improve consumer welfare.	Sunstein (2020), Bonroy and Constantatos (2015)
Other choice architectures incl. retail store and menu engineering	Interventions that alter the properties or placement of objects or stimuli within microenvironments to change health-related behaviour.	Different combinations and combined effectiveness of place, profile, portion, pricing, promotion, healthy default picks, prompting or priming and proximity).	Kraak et al (2017)
Other behavioural interventions	Soft-paternalism - suite of measures applicable in a variety of food choice contexts including default rules, implications, social norm messaging and warnings.	Largely used in combination with food advertising, retail, restaurant and home cooking contexts. Limited research evaluating shift from meat consumption.	Reisch et al. (2021), See also WRI (2020)
Waste	Messaging display until rather than sell/use-by dates, reduced portion sizes, household waste reduction targets and specific bin charges.	Use in combination with choice architecture and other behavioural interventions - e.g. specific bins, advice on meal planning and social interaction, downsizing the plate, removing trays and reducing supermarket choices. Some waste unavoidable.	von Kameke and Fischer (2018)
Local and direct marketing	Measures appealing specifically to the reduction of food miles and the promotion of local economies.	Limited seasonal choice and the fact that to reduce emissions what you eat (and effect on land use) is much more important than whether your food is local.	Poore and Nemecek (2018)
Corporate investment exposure/legal liability	Institutional investors, banks and insurers seeking to minimise their exposure to climate risks including reducing investment in agri-food.	An evolving indirect demand pressure on production and consumption patterns. Legal precedents as yet untested.	FAIRR (2019)
Prohibition/bans (on consumption)	Strong paternalism, mandating specific consumption and marketing practices.	Governments typically averse to intervening in consumer choice relative to production practices, although experience with banning food waste locally (Vermont) and (public) institutional decisions not to serve meat products. Public health and environmental outcomes can be ambiguous.	Angell et al. (2012)

Abbreviation: GHG = greenhouse gas.

meat), with potential regionalisation driven by shifts in relative factor input costs (land, labour and capital), and the stringency of emerging production and consumption-side regulation, and relative ability to minimise/internalise some of the external costs outlined here; the latter driven by the adoption of new technologies including precision feeding and genetics. Expressed in this way, environmental, health and cultural attributes of livestock production become additional factors of regional comparative advantage likely to pit northern temperate producers (mostly EU and North America) with competition from countries such as Brazil and Argentina. In these scenarios, the shape of government support to the provision of public goods and potential trade barriers will be significant determinants of viability. So too will domestic regulatory and international trade restrictions that aim to level the environmental playing field, for example, the use of a carbon border adjustment mechanism, for selected sectors, to reduce the risk of carbon leakage between regulated and unregulated countries. This would ensure that the price of imports reflects more accurately their carbon content.

Challenging the instrumental neoclassical (economic) frame reveals more fundamental philosophical caveats to the issue of equating sustainability with correcting market failure by internalizing costs. The first has been raised in the context of animal welfare and genetic modification, and relates to the notion of value pluralism and intrinsic value in particular, which posits a non-instrumental value outside any anthropocentric utilitarian frame-

work. The implications are problematic, implying the illegitimacy of subjecting other life forms to the whims of human preferences.

Beyond the instrumental/intrinsic dichotomy, value pluralism includes relational values, i.e. human relationships with nature/animals and each other. They also include physical, mental and emotional health, way of life, cultural identity, sense of place and social cohesion. As advocated by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (see Pascual et al 2017), the approach is sensitive to the plurality of worldviews and diversity of values. However, while recognizing the validity of pluralism, the stance implies that valuation trade-offs cannot easily be made. For example, negotiating a world where intrinsic value is widely assigned, policy development must accommodate the constraint of some absolute values.

The second caveat is that internalisation follows from one specific definition of sustainability, which assumes that the resulting livestock optimum will fall within some predetermined biophysical or socially defined planetary boundaries or safe operating space (**SOS**). While some attempt has been made to define metrics of a SOS for the EU (Buckwell and Nadeu, 2018), its national and global policy interpretation is more controversial. Arguably if livestock emissions are essentially avoidable compared to say those from energy generation, then a SOS is technically defined by the relative costs of reducing emissions and could be globally very low.

Both caveats lead to a different philosophical approach that foregrounds non-negotiable boundaries and a version of strong rather than weak sustainability. This distinction is one that recognises some non-negotiable system boundaries, limits of substituting man-made capitals for depleted natural capital and ultimately limits to unfettered economic growth (Barbier and Burgess, 2017). These differences are defining attributes of the field of Ecological Economics, in counterpoint to more mainstream neoclassical environmental economics (Illge and Schwarze, 2009).

Conclusion

Evolving health and environmental consequences of meat consumption will exert increasing pressure on the ways that livestock are reared and produced. The market is also being disrupted by new substitute products that are deliberately marketed in counterpoint to the impacts of conventional meat. The growing global debate about livestock juxtaposes dietary and global environmental concerns in upper-income countries, with livelihood considerations in countries where demands are nascent. The evolving preferences imply segmented meat demands, and associated transformation of production systems as countries grow, and more specialised market niches emerge. A longer-term dietary transition is likely to evolve into a more homogenised convergence on desirable attributes as external costs are more consistently regulated in all countries or even globally through a carbon price.

In many parts of the world, rearing livestock for consumption is arguably a choice rather than a necessity. If as individuals or a society we choose to maintain the sector, then we should do so with the clearest view of the costs and benefits of our decision using a framework that facilitates commensurability of impacts. A neoclassical framing can help, but should acknowledge the limits defined by the rhetoric of planetary boundaries and with regard to a clearer definition of sustainability.

Consumer preferences are mediated by markets, and so far, markets are evolving slowly to afford consumers agency over important dimensions of their choices. There are also relatively few government mandated demand-side restraints on consumption choices. However, the growing relative share of external costs from the livestock sector suggests this is unsustainable and there is a role for alternative forms of government intervention. Livestock scientists need to anticipate likely behavioural, market and government interventions moving us away from the status quo. Increasing scrutiny suggests that ultimately the sector will need to demonstrate and earn a new social licence to operate.

Ethics approval

None.

Data and model availability statement

No relevant data consideration and none were deposited in an official repository.

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Declaration of interest

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